<u>Jon B. Betts</u>

<u>Transport measurements in pulsed magnets.</u>

I. Methods of sample preparation for measurements of R and R hall, including discussions of sample size, orientation and electrical contacts will be presented.

II. Sample probe construction for both high and low impedance measurements.

III. Pros and cons of traditional and digital lockin techniques.

IV. A discussion of “what can go wrong” including sample heating, out of phase signals and field induced wire motion.

V. <u>Practical</u>

Make a resistance measurement using high frequency excitation.

Demo of capacitance losses in long cables.

<u>Measuring heat capacity in high DC magnetic fields.</u>

I. Review the different methods of measuring heat capacity including classic relaxation, dual slope relaxation and AC methods.

II. Discuss the hardware setup that we use including calorimeter and cryogenics design.

III. Electronics and data taking, how to reduce scatter.

IV. <u>Practical-</u>Measure exponential curves on a room temperature platform.

<u>Greg Boebinger</u>

<u>The Versatility of Magnetic Fields in Condensed Matter Physics, Chemistry and Biology</u>

The world’s most powerful electromagnets (>1,000,000 the Earth’s magnetic field) are developed and utilized at the National High Magnetic Field Laboratory (the MagLab). This talk answers the question….’why would anyone do such a thing?’…as applied to the frontiers of knowledge in condensed matter physics, chemistry and biology. Primary research areas include (a) Quantum Matter, addressing our limited understanding of strongly interacting electron systems; (b) Complex Fluids, such as petroleum and pharmaceuticals; (c) Magnetic Resonance of both nuclei (NMR) and electrons (EMR) to understand metallo-proteins, molecular magnets, and catalysts, (d) and Magnetic Resonance Imaging of living brains. Expressed differently: (a) applying the energy of 200 sticks of dynamite to slightly perturb electrons; (b) weighing molecule mixtures as nature provides them…messy, very messy; (c) playing ‘Where’s the spin?’ with the entire periodic table; and (d) the printing the High-Definition ‘Mouse Brain Atlas’. **Jokes will be told.**

<u>A “Big Light” Terahertz-to-Infrared Laser: *Condensed Matter Physics, Chemistry and Biology in the Notorious 'Terahertz Gap'*</u>

The 'Terahertz (THz) Gap' represents a ‘blindspot’ in the electromagnetic spectrum sitting between electronics (up to gighertz) and infrared (IR) optics. After a successful design collaboration with Jefferson Laboratory, we are proposing to construct a world-unique THz to IR ("THIR") light source alongside the MagLab. “Big Light” will be tunable over the entire range bridging the Terahertz Gap, providing picosecond light pulses of unrivalled brightness (one million times the THz brightness available at present-day synchrotrons). It will feature a first-ever flexibility for 'pump/probe' experiments, the capability to simultaneously produce pulses of two different colors that are time-synchronized to within 20 femtoseconds. My talk will review the scientific case for the $60M Big Light project, with a particular emphasis on applications in condensed matter physics, chemistry and biology.

Jim Brooks

The vector potential and other exotica in high field and low temperature experiments

This presentation will focus on some of the more unusual, clever, and/or extreme investigations that have been performed, or have been contemplated, in high magnetic field science. Both experimental methods and the resulting science (or the expected science) will be discussed for some specific cases. Topics to be considered, depending on the audience, may include the quantum interference of electrons, superconductivity living in high fields, doing Terahertz EPR in the Hybrid, getting 12 T out of a 9 T superconducting magnet, otherwise boring silicon in high magnetic fields, why waxed dental floss is best, how would your sample behave if you placed it half way to the center of the earth, synchrotron radiation for the masses, and time permitting, what to do when your 4-terminal measurement becomes a 3-terminal measurement, and then a two terminal measurement, and then… a one terminal measurement?

Eun Sang Choi

Magnetometry at the NHMFL: a practical guide to ac susceptometer, torque magnetometer, VSM users

Magnetometry is very popular and useful method of modern natural science. The NHMFL user program provides a range of magnetometers for different applications. We will survey the characteristics of the magnetometers covering their ranges, sensitivities, practical instrumentations and so forth. A greater focus will be placed on most widely used ones at Tallahassee; ac susceptometer, torque magnetometer and vibrating sample magnetometer (VSM). A practical guide intended for experimentalists who want to use/develop such magnetometers will be given. We will also present a high pressure VSM system and some other magnetometers under development.

Michael W. Davidson

Optical Microscopy for the Material Sciences

Reflected light microscopy is one of the most common techniques applied in the examination of the opaque specimens commonly encountered in the materials sciences, which are usually highly reflective and, therefore, do not absorb or transmit a significant amount of the incident light. Slopes, valleys, and other discontinuities on the surface of the specimen create optical path differences that are transformed by reflected light differential interference contrast (DIC) optical components into amplitude or intensity variations that reveal a topographical profile. Students will learn the basics of reflected light microscope configuration, digital imaging, and sample preparation techniques.

In reflected light DIC microscopy, the optical path difference produced by an opaque specimen is dependent upon the topographical geometrical profile (surface relief) of the specimen and the phase retardation that results from reflection of sheared and deformed orthogonal wavefronts by the surface. For a majority of the specimens imaged with DIC, the surface relief varies only within a relatively narrow range of limits (usually measured in nanometers or micrometers), so these specimens can be considered to be essentially flat with shallow optical path gradients that vary in magnitude across the extended surface. Phase changes occurring at reflection boundaries present in the specimen also produce and optical path difference that leads to increased contrast in the DIC image. These phase differentials are more likely to be found at junctions between different media, such as grain boundaries and phase transitions in metals and alloys, or aluminum and metal oxide regions in a semiconductor integrated circuit.

Although reflected light DIC microscopy has been heavily employed for examination of metallographic specimens for the past few years, currently the most widespread and significant application is the examination of semiconductor products as a quality control measure during the fabrication process. In fact, most of the manufacturers now offer microscopes designed exclusively for examination of integrated circuit wafers in DIC, brightfield, and darkfield illumination. DIC imaging enables technicians to accurately examine large volumes of wafers for defects that are not revealed by other microscopy techniques. Minute variations in the geometrical profile of the wafer surface appear in shadowed relief, and maximum image contrast is achieved when the Nomarski prism setting is adjusted to render the background a neutral gray color.

Zhehong Gan

NMR for Chemistry and Biology

NMR applications of large molecules rely on signal intensity and resolution for observing and distinguishing various atomic sites. I will give an overview on the development of NMR from physics to chemistry and biology, basic principle of multi-dimensional NMR spectroscopy and various techniques for enhancing NMR sensitivity and resolution. The talk will also include some recent development on quadrupolar nuclei NMR of which high magnetic fields are very important for the spectral resolution and sensitivity.

Samuel C. Grant

Exploring the Limitations and Capabilities of High Field MR

The evolution of magnetic resonance instruments to higher field strengths mandates continued improvement in associated hardware technologies and acquisition techniques. Radio frequency coil designs, gradients and amplifiers must be optimized to the challenges of increased operating frequencies and unique samples of interest. Additionally, the common rules of image contrast at clinical filed strengths require redefinition at high fields. This presentation details some of the challenges and rewards of performing research at ultra-high magnetic fields.

To begin, relevant issues of high field MR will be reviewed with emphasis on the RF concerns that arise when working with relatively large structures and emergent contrast mechanisms. For example, observations of signals voids caused by dielectric-induced standing waves will be presented. These artifacts severely affect the homogeneity of proton MRI and have a serious impact on the feasibility and future directions of high field MRI. Field-related changes in image contrast also will be discussed, particularly with respect to relaxation mechanisms.

Meeting these challenges and utilizing the benefits of high field MR, on-going microimaging and microspectroscopy efforts at 21.1 T will be discussed. These experiments involve *in vivo, ex vivo* and *in vitro* specimen ranging from living rodents to single neurons that use high fields and optimized RF hardware to achieve image resolutions of less than 10 μm and localized spectroscopic voxels of less than 10 nL. In addition, acquisition techniques are being pursued to recover image contrast and exploit emerging contrast mechanisms (e.g. dipolar fields). These studies also include materials examinations of contrast agents in an effort to improve the sensitivity of molecular imaging probes. Recent investigations have made use of these benefits to examine the organization of anatomical microstructures in response to genetic mutations, pathologies and environmental factors as well as the fundamental origins of MR signal and contrast in a wide range of samples.

Scott Hannahs

Data Acquisition

The success of running up an experiment depends on getting the data in a form that can be analyzed at the end. Discussion will cover the entire process from instrumentation to analysis.

Measurements

Digital Measurements
Data Communication
Noise Considerations
Data Rates

Programming a data Acquisition system

Asynchronous Operation
Parallel Operations
Automating an Operation
Open Loop vs. Closed Loop control
Data Formats

Data organization

Metadata
Cataloging Data
Archiving Data
Tracing the Analysis
Documenting Methods

Practical exercise: Set up a measurement per schematic

One of the primary skills for an experimentalist is setting up a measurement from a sometimes vague description. This exercise will go over setting up a complex measurement with from a schematic. We will cover the practical setting up of a measurement system. Attention will be paid to ability to verify the system, troubleshooting, and reliability. We will also look at how the measurements perturb the experimental environment. A comparison of connectors, cables and common mistakes will be discussed.

Neil Harrison

Fermi surfaces in Extreme Magnetic Fields

Sometimes, the only way to understand the electronic structure of a metal and to understand the nature of the elementary excitations is to perform magnetic quantum oscillation measurements. Such measurements are required to identify the true electronic structure and understand the nature of the elementary excitations. In the vast majority of metals these kinds of measurement can be made using superconducting magnets and a suitably equipped measurement detection system involving a modulation of the magnetic field. However, some materials, especially strongly correlated materials, require much stronger magnetic fields to see the Fermi surface. Changes in the experimental methods are required— especially in pulsed magnetic field experiments where the magnetic fields are of short duration. For systems with large Fermi surfaces (i.e. many carriers), one can often measure magnetic quantum oscillations with wire wound magnetometers. However, in some of the more exotic systems, including underdoped high Tc cuprates and Fe-As-based pnictide superconductors, the pockets of Fermi surface are very small. Measurement of the contactless conductivity (at radio frequencies) and the use of micromachined cantilevers provide alternatives that have recently proven to be very fruitful is these materials.

Christopher L. Hendrickson

High-Field Fourier Transform Ion Cyclotron Resonance Mass Spectrometry

Mass spectrometer sales exceed $2B annually, due largely to unique analytical advantages of mass analysis in environmental and life sciences. Fourier transform ion cyclotron resonance (FT-ICR) offers the highest resolving power and mass measurement accuracy and precision of any mass analyzer. In this talk, we review the physics of FT-ICR, which underscores the need for A BIG MAGNET! At least nine performance parameters scale linearly or quadratically with magnetic field strength, including mass resolving power, mass accuracy, measurement speed, and mass spectral dynamic range. We describe current capabilities at 9.4 and 14.5 tesla (e.g., mass resolving power is routinely greater than 200,000 at m/z 400 at 1 measurement per second, and mass measurement accuracy is typically better than 300 parts-per-billion rms, even when >10,000 analytes are measured simultaneously!) and efforts toward 21 tesla. In addition to field strength, magnet characteristics such as field homogeneity, temporal stability, stray field, size, and cryogenic performance are critical. Ion sources, ion optics, vacuum pumps, photons, and electrons must work in harmony with the magnet. We'll cover current methodology, and highlight a few examples of what not to do.

Stephen Hill

Applications of Electron Magnetic Resonance at the NHMFL

This tutorial talk will provide a broad overview of the many high-field applications of Electron Magnetic Resonance (EMR) spectroscopy in condensed-matter physics, chemistry and biology. A magnetic field couples to both the spin and orbital degrees of freedom of atomic, molecular and/or itinerant band electrons in solids, giving rise to new energy splittings. The approximate frequency/energy scale associated with both of these interactions is 28 GHz/tesla (assuming a free electron mass and a g-factor of 2). However, the exact spectrum is highly sensitive to details of the electronic structure. EMR includes electron spin resonance (ESR) and cyclotron resonance (CR), which are very precise magnetooptical spectroscopies that respectively probe the spin and orbital excitation spectra of electrons in solids, thus providing detailed information about both the static and dynamic properties of molecules or crystals, i.e. EMR talks to electrons which, in turn, provide local snapshots on a frequency (energy) scale corresponding to ~28 GHz/tesla (~0.1 meV/tesla). The extension of EMR to high fields is challenging, because excitations extend well into the notorious 'Terahertz Gap' (100 GHz to 3 THz) where almost no technology exists for generation and detection of electromagnetic signals. Nevertheless, high-fields and frequencies provide access to important energy and time windows that are inaccessible using commercial low-field spectrometers. Thus, EMR represents an important component of the activities at any high magnetic field laboratory.

Jan Jaroszynski

I. Noise suppression

In common use, the word noise means unwanted sound or noise pollution. In electronics noise can refer to the electronic signal corresponding to acoustic noise (in an audio system) or the electronic signal corresponding to the (visual) noise commonly seen as 'snow' on a degraded television or video image. In signal processing or computing it can be considered data without meaning; that is, data that is not being used to transmit a signal, but is simply produced as an unwanted by-product of other activities.

In physics, on the one hand, the nature of the noise and its characteristic are subject of intensive studies. The noise can serve as a powerful tool to investigate physical phenomena and materials. For instance the 1998 Nobel Prize was awarded for discovery of the fractional electric charge in the fractional quantum Hall regime only after it was independently confirmed by measurements of shot noise indeed revealing fractional electric charge. On the other hand, experimental physicists often find the noise as an obstacle in getting clean data. If signal to noise ratio is small the measurements are difficult, not accurate and sometimes impossible. It happens for instance when the measuring setup is close to the source if intense electromagnetic radiation, as large transformer or electric motor. Sometimes external electromagnetic noise makes not only the measurements difficult itself, interfering with the experimental setup, but also changes the physical system under study. For instance, this is the case at very low temperatures, when high frequency electromagnetic radiation from nearby radio station warms up electrons in the sample, making temperature measurement unreliable.

We will talk about the most common noise phenomena observed in physical and other systems, as thermal noise, pink noise, shot noise etc.

II. Practical

How to suppress unwanted noise and how to get as clean signals as possible by means of proper experimental setup architecture, grounding, shielding, filtering, use of proper cables, connectors etc. Troubleshoot the small signal to noise ratio, how to diagnose the problem and how to improve the measurement. The focus will be put on electric transport measurement at high magnetic fields but many methods are quite general. All the above will be illustrated by simple in class demonstrations.

David C. Larbalestier

Superconductors for Superconducting Magnets

Applied Superconductivity Center, National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL 32310, USA

There are over 5000 superconducting materials but only about 5 have ever been useful for applications in magnets. Although you have spent all week learning exactly why the NHMFL is *the* best place in the world for doing experiments in very high fields, what you have learned about the NHMFL DC magnets is *not* transferable. The utterly crucial (and unfair?) advantage of the lab is that it has over 50 MW that it can efficiently apply to heat up copper discs that make the most intense DC fields (35 T when purely resistive and 45 T when backed by a superconducting magnet) on earth. In your own laboratories it is likely that you generate less intense fields (~21 T max) using superconductors. Most of the time you probably use superconducting magnets made out of a simple bcc alloy Nb-Ti (up to ~10 T) or the A15 structure intermetallic Nb_3Sn (up to about 21 T). These two materials are easily made into wires with specific structures consisting of, typically, many hundreds or thousands of superconducting filaments a few mm in diameter, each surrounded by normal metal that carry the current temporarily if superconductivity is lost. Given the high electromagnetic forces of powerful magnets, strength in the conductor is also important. Although Nb is a relatively expensive metal, Nb-base conductors with copper as their surrounding normal metal matrix, are cost-effective tools for making powerful magnetic fields well above the ~2 T possible by using the saturation of ferromagnets like Fe. But Nb-Ti and Nb_3Sn are staid materials far from the cutting edge of present condensed matter studies. Cuprates like $YBa_2Cu_3O_{7-x}$ and $Bi_2Sr_2CaCu_2O_x$ do remain at the scientific forefront, as do the recently discovered Fe-As pnictide superconductors. What has to be done to make them useful for magnets, given that they have many times the critical current density J_c and 3 times the upper critical field H_{c2} (more than 100 T)? In cuprates the biggest problem in making conductors has been the need for extreme texture (“single crystals by the mile”) so as to avoid grain boundaries which impede current flow, but round multifilament wires of $Bi_2Sr_2CaCu_2O_x$ are now available and in 2008 we at the NHMFL were able to make a working magnet which generated 1T in a 31 T background. With YBCO we were even more successful, achieving almost 3 T in 31T background. These tests have convinced us that an all-superconducting 32 T user magnet (consuming less than 1 kW, primarily in cooling power) is now feasible and we have made such a proposal to the NSF. At the same time the pnictides are showing that much lower anisotropies are possible in layered compounds and that current transport across grain boundaries may be less compromised than in the cuprates. All of these discoveries are combining to make the applications of superconductors almost as exciting as their science!

Ross McDonald

Practical Exercise: Cantilever Magnetometry

Set up the micro-manipulator to give students some hands on experience mounting ~100μm^2 samples on a lever (~120*40μm). Set up a bridge circuit with a synchronous lockin to demonstrate how we measure small changes in resistance with short time constants. Dielectric resonator--find and tune the resonances.

Chuck Mielke

The TDO and Beyond: Contactless Methods for High Precision Measurements of Electrical Resistivity

The use of contactless methods for determination of the electrical resistivity and the magnetoresistance of metals has recently proven to be an efficient and precise method for determination of small changes in the response of metals and superconductors to external perturbations. How far can this method be pushed? Are microsecond magnetic field pulses too fast for this method? Can the absolute resistivity be determined from the technique? Is there a modern version of the technique? A practical review of the method and its 50 year history will be explained. Students will come away with knowledge of how to build and apply this powerful technique in their own research environments.

Pulsed Field Facility

The highest magnetic field research takes place in a research instrument that is brought to within a few percent of total destruction on a routine basis. The pulsed Field Facility of the NHMFL has a broad spectrum of magnet systems that provide magnetic fields from 50 tesla to 240 tesla the duration of the pulses are as long as 2.5 seconds to as little as 6 micro-seconds. The research capabilities span from acoustics to Zeeman band splitting. A review of the capabilities and a brief introduction to pulsed magnetic field generation will be discussed.

Albert Migliori

There will be no jocularity

Summer School: Introduction, Expectations, Agenda

Noise:

I. Noise and interference

- a. Intrinsic limits on noise and interference.
- b. Grounding and team noise

II. Detection of low-level ac signals

- a. General principles.

b. Heterodyne detection.
c. Homodyne detection and Lock-In amplifiers.

III. Digital Signal Processing
a. Intrinsic limits.
b. A digital replacement for the Lock-In amplifier.
c. The latest out of NHMFL

Ultrasound

The speed of sound is one of the most fundamental and most often measured attributes of a solid. The elastic stiffnesses of a solid can be determined with outstanding precision. Together with density, the stiffnesses control the speed of propagation of stress waves (sound) and depend on the variation of fundamental thermodynamic quantities—internal energy or free energy—with deformation. Unlike most of the quantities used to characterize condensed matter, the elastic moduli are fourth-rank tensors containing a wealth of detail, directional information, and consistency constraints that provide one of the most revealing probes of solids. This talk describes two techniques, pulse-echo ultrasound and resonant ultrasound spectroscopy, that condensed matter physicists now use to probe solids in NHMFL magnets.

Tim Murphy

Cryogenic Techniques for High Magnetic Field Experiments

Many experiments at the NHMFL DC Field Facility are conducted at or below 4.2 K. The design and complexity of the necessary cryogenic equipment is dictated both by the lowest temperature needed as well as the physics being studied in the low temperature / high magnetic field environment. This session will include techniques used to produce low and ultra low temperatures and the way in which these techniques are employed at the NHMFL. Thermometry, temperature stability and commonly encountered challenges will be discussed such as eddy current heating, joule heating and kapitza resistance. This talk will also be an introduction to probe, sample holder & cryostat design for high field experiments.

Eric Palm

The Do's and Don'ts of Running in the DC Field Facility

An overview of the DC Field facility will be presented. Best practices relating to how to set up an experiment, grounding, other generalities will be discussed. In addition, what users should expect from a visit to the MagLab and how to best plan and prepare to maximize their use of the DC Facility will be presented.

Measuring resistivity and Hall resistance in DC magnetic fields.

Though measuring resistivity may appear to be one of the easiest measurements to make, doing it correctly requires care. The ABC's of resistance measurements will be outlined. Potential sources of error such as Joule or eddy current heating will be described with prescriptions given for how to test for and avoid these errors. Difficult measurements such as measuring samples with very high or low resistivity will also be discussed. Both AC and DC measurement techniques will be presented with practical advice about instrument selection. In addition, a number of recipes for creating low resistance contacts to samples will be given. The practical session will consist of students mounting a sample, cooling it to find its superconducting transition then sweeping the magnetic field to determine its critical field.

Ryan Rodgers

Petroleum Analysis by Fourier Transform Ion Cyclotron Resonance Mass Spectrometry

To meet the world's energy demand, oil companies around the world are tapping into heavier, more viscous petroleum reserves that contain higher amounts of (undesirable) heteroatoms such as sulfur, oxygen, nitrogen and metals. In order to process heavier crudes into usable products, the offending heteroatoms must be removed. However, due to the complexity of the heavy crudes, detailed compositional information is difficult to obtain. Equipment designed and built here at the National High Magnetic Field Lab called FT-ICR mass spectrometers, have shown great promise in the detailed compositional analysis of crude oils. The inherent high mass accuracy and high mass resolving power of FT-ICR MS provides for the elemental composition assignment of thousands of different polar heteroatom containing species from a single crude oil.[1] Similar results have also been achieved for asphaltenes and coal derived materials.[2] Here we briefly present an overview of FT-ICR MS and its application to petroleum characterization. Included are applications focused on naphthenic acid characterization, emulsion characterization, live and dead oil analysis, reservoir biodegradation studies, and deposit/asphaltene characterization. Recent advances in ionization methods have led to the expansion of the technique to nonpolar species characterization. Specifically, Atmospheric Pressure Photoionization (APPI) FT-ICR MS has recently been applied to both whole and SARA fractionated oils that highlight both aromatic hydrocarbon and nonpolar Sulfur species of interest. The presentation will highlight data visualization/reduction techniques that have proven effective in highlighting FT-ICR MS results.

1) Qian, K.; Rodgers, R.P.; Hendrickson, C.L.; Emmett, M.R.; Marshall, A.G. *Energy & Fuels* 2001, *15*, 492-498.
2) Wu, Z.; Jernström, S.; Hughey, C.A.; Rodgers, R.P.; Marshall, A.G. *Energy & Fuels* 2003, 17(4), 946-953.

Dmitry Smirnov

Infrared and THz spectroscopy at high magnetic fields

This tutorial will provide an overview of the infrared (IR) and THz capabilities adapted to operate at low temperatures with the high-field DC magnets available at the NHMFL. IR and THz regions extend from visible light to microwaves covering the broad range electromagnetic spectrum, typically from 1 um to 1 mm in wavelength (300 THz – 0.3 THz, 10000 cm^{-1} – 10cm^{-1}, 1 eV – 1meV). To probe the interaction between light and matter at high magnetic fields and in such a wide range of energies, appropriate techniques and apparatus should be used. These techniques (broad band transmission, reflectivity, emission, photo-conductivity, as well as magnetic resonances spectroscopy) are described and will be used as a basis to discuss the use of the experimental apparatus: Fourier-transform infrared spectrometers, tunable (backward wave oscillators) and single-line (lasers) sources, IR/THz optics and detectors, sample probes. Finally, commonly used methods of interpretation of optical experiments (Kramers-Kronig analysis, spectra fitting routines, etc.) will be briefly reviewed.

Neil Sullivan

Ultra-Low Temperature Experiments

This tutorial will provide guidance for scientists who are not necessarily expert in low temperature techniques on how to design and carry out experiments in the 0.2 to 20 mK range and in high magnetic fields (currently up to 16 T) simultaneously. These high field –low temperature conditions are in some cases critical for determining the ground state symmetry properties of materials, exploring quantum phase transitions, and to study the dynamics of collective ordering in quantum fluids and solids, such as the “alleged” supersolid phase of 4He and new even denominator fractional quantum Hall states.

The tutorial will outline what kinds of experiments can be carried out, the problems of reducing the heat input from the experiment and leads connecting to experiment, the challenges of reliable thermalization and temperature measurements at very low temperatures. Some illustrative examples will be reviewed, including thermodynamic measurements of materials (pressure, magnetization, temperature) to determine phase diagrams (superfluid 3He, BEC magnon condensed states), pulsed NMR at very high frequencies to below 1 mK (transport studies in superfluids), and how to rotate samples in high fields.

We will also review how experiments should be prepared, the allowable cooling and warming cycles, and how to optimize experiments to minimize liquid helium costs.

Stan W. Tozer

High Pressure Methods for Extreme-Condition Research

Pressure is a useful variable when exploring the physics that controls a material's behavior. Methods to carry out a variety of experiments (NMR, resistivity, dHvA and SdH and optical) at extreme conditions of pressure, high magnetic fields and low temperatures will be presented. The tradeoffs between sample size (high pressure volume), the desired pressure range, cryogenic restrictions that dictate cell size, the need to rotate and the degree of hydrostaticity will be explored. Demonstrations will be given on means to make mechanically and electrically viable contacts and leads to samples and we will discuss new technologies to do so with designer stones. The basics of cell designs for large and small volume high pressure work, DC and pulsed field work and the selection of anvils and materials will be explored.

Vivien Zapf

Dilatometry

Dilatometry, thermal expansion, and magnetostriction are all different names for measuring of the length changes of a sample as a function of temperature or magnetic field. Combined with specific heat, magnetization, and thermal conductivity, dilatometry can provide a complete thermodynamic picture of a magnetic system. In addition, it can detect structural transitions with phenomenal sensitivity, and help us understand how the magnetic forces distort the lattice of a crystal. Among other things, spin lattice coupling can be a route to magnetoelectric behavior, or can turn a second order transition into a first-order one.

In the past few years a collaboration with George Schmiedeshoff at Occidental college has led to the development of a new dilatometry cell that has been implemented in Tallahassee and Los Alamos and can provide sub-Angstrom resolution measurements of length changes down to dilution refrigerator temperatures and up to 45 T. I will review the science behind this technique, and discuss some tricks and pitfalls to performing the measurements. Finally I will present recent examples of how dilatometry has been applied to yield insights into strongly correlated electron systems and quantum magnets.